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Means and Method for assessing the geometry of a subterranean fracture after or during a hydraulic fracturing treatment

Technical Field of the Invention

[0001] This invention relates generally to the art of hydraulic fracturing in subterranean formations and more particularly to a method and means for assessing the fracture geometry after or during the hydraulic fracturing.

Background of the Invention

[0002] Hydraulic fracturing is a primary tool for improving well productivity by placing or extending channels from the wellbore to the reservoir. This operation is essentially performed by hydraulically injecting a fracturing fluid into a wellbore penetrating a subterranean formation and forcing the fracturing fluid against the formation strata by pressure. The formation strata or rock is forced to crack, creating or enlarging one or more fractures. Proppant is placed in the fracture to prevent the fracture from closing and thus, provide improved flow of the recoverable fluid, i.e., oil, gas or water.

[0003] The proppant is thus used to hold the walls of the fracture apart to create a conductive path to the wellbore after pumping has stopped. Placing the appropriate proppant at the appropriate concentration to form a suitable proppant pack is thus critical to the success of a hydraulic fracture treatment.

[0004] The geometry of the hydraulic fracture placed affects directly the efficiency of the process and the success of the operation. This geometry is generally inferred using

models and data interpretation, but to date, no direct measurements are available. The present invention is aimed at obtaining more direct measurements of the fracture geometry (e.g. length, height away from the wellbore).

[0005] The fracture geometry is often inferred through use of models and interpretation of pressure measurements. Occasionally, temperature logs and/or radioactive tracer logs are used to infer fracture height near the wellbore. Microseismic events generated in the vicinity of the created hydraulic fracture are recorded and interpreted to indicate the direction (azimuth) and length and height of the created fracture.

[0006] However, these known methods are indirect measurement, and rely on interpretations that may be erroneous, and are difficult to use for real-time evaluation and optimization of the hydraulic fracture treatment.

[0007] It is therefore an object of the present invention to provide a new approach to evaluate the fracture geometry.

__Summary of the Invention__

[0008] According to the present invention, the fracture geometry is evaluated by placing inside the fracture small devices that, either actively or passively, give us measurements of the fracture geometry. Fracture materials (small objects with distinctive properties e.g. metal beads with very low resistivity) or devices (e.g. small electronic or acoustic transmitters) are introduced into the fracture being pumped during the fracture treatment with the slurry.

[0009] According to a first embodiment of the present invention, active devices are added into the slurries. These devices will actively transmit data that provide information on the device position and thereafter, can be associated with fracture geometry.

[0010] According to another embodiment of the present invention, passive devices are added into the slurries. In the preferred embodiment, these passive devices are also used as proppant.

__Detailed description and preferred embodiments__

[0011] Examples of "active" device include electronic microsensors , for example such as radio frequency transmitter, or acoustic transceivers of acoustic or electromagnetic

waves. These "active" devices will be integrated with location tracking hardware to transmit their position as they flow with the fracture fluid/slurry inside the created fracture. The microsensors can be pumped with the hydraulic fracturing fluids throughout the treatment or during selected strategic stage of the fracturing treatment (pad, forward portion of the proppant-loaded fluid, tail portion of the proppant-loaded fluid) to provide direct indication of the fracture length and height. The microsensors could use wireless links to neighboring microsensors and location and positioning capability through for example local positioning algorithms.

[0012] Pressure and Temperature sensors could also be integrated with the above-mentioned active devices. The resulting pressure and temperature measurements would be used to better calibrate and advance the modeling techniques for hydraulic fracture propagation. They would also allow optimization of the fracturing fluids by indicating the actual conditions under which these fluids are expected to perform. In addition chemical sensors could also be integrated to allow monitoring of the fluid performance during the treatment.

[0013] Since the number of active devices required is small compared to the number of proppant grains, it is possible to use devices significantly bigger than the proppant pumped in the fracturing fluid. The active devices could be added after the blending unit and slurry pump, for instance through a lateral by-pass.

[0014] A recorder placed downhole in the wellbore, or at surface, would capture and record/transmit the data sent by the devices to a computer for further processing and analysis. The data could also be transmitted to offices in any part of the world using the Internet to allow remote participation in decisions affecting the hydraulic fracturing treatment outcome.

[0015] Should the devices signal become too weak to be picked up by the recorder, the devices injected could be programmed to relay the signal from the farthest devices towards the devices still closest to the recorder to allow uninterrupted transmission and capture of data. The idea is to easily deploy smart devices with one or multiple on-board sensors, networked through wireless links.

[0016] Should the frequency range utilized by the electronic transmitter be such that the borehole metal casing would block its transmission to the wellbore recorder/transmitter, antennas could be deployed across the perforation tunnels. These antennas could be mounted on non-conductive balls slighltly larger than the perforation diameter and designed to be pumped and to seat in some of the perforations and relay the signals across the metallic casing wall. An alternative method of deployment would be for the transmitter to trail an antenna wire while being pumped.

[0017] A further variant would cover the case where the measuring devices are optical fibers with a physical link to a recorder in the borehole that would be deployed through the perforations when the well is cased perforated or directly into the fracture in an open hole situation. The optical fiber would allow length measurements as well as pressure and temperature.

[0018] An important alternative embodiment of this invention covers the use of materials with specific properties that would enable information on the fracture geometry to be obtained using an additional measurement device.

[0019] Specific examples of "passive" materials include the use of metallic fibres or beads as proppant. These would replace some or all of the conventional proppant and may have sufficient compressive strength to resist crushing at fracture closure. A tool to measure resistivity at varying depths of investigation would be deployed in the borehole of the fractured well. As the proppant is conductive with a significant contrast in resistivity compared to the surrounding formations, the resistance measurements would be interpreted to provide information on fracture geometry.

[0020] Another example is the use of ferrous/magnetic fibers or beads. These would replace some or all of the conventional proppant and may have sufficient compressive strength to resist crushing at fracture closure. A tool containing magnetometers would be deployed in the borehole of the fractured well. As the proppant generates a significant contrast in magnetic field compared to the surrounding formations, the magnetic field measurements would be interpreted to provide information on fracture geometry. According to a variant of this example, the measuring tools are deployed on the surface or in offset wells. More generally, tools such as resistivity tools, electromagnetic devices,

and ultra long arrays of electrodes, can easily detect this proppant enabling fracture height, fracture width, and with processing, the propped fracture length to some extent can be determined.

[0021] A further step is covered whereby the information provided be the techniques described above would be used to calibrate parameters in a fracture propagation model to allow more accurate design and implementation of fractures in nearby wells in geological formations with similar properties and immediate action on the design of the fracture being placed to further the economic outcome.

[0022] For example, if the measurements indicate that the fracture treatment is confined to only a portion of the formation interval being treated, real time design tools would validate suggested actions, e.g. increase rate and viscosity of the fluid or use of ball sealer to divert the fluid and treat the remainder of the interval of interest.

[0023] If the measurements indicate that the sought after tip screenout did not occur yet in a typical Frac and Pack treatment and that the fracture created is still at a safe distance from a nearby water zone, the real time design tool would be re-calibrated and used to validate an extension of the pump schedule. This extension would incorporate injection of additional proppant laden slurry to achieve the tip screenout necessary for production performance, while not breaking through into the water zone.

[0024] The measurements would also indicate the success of special materials and pumping procedures that are utilized during a fracture treatment to keep the fracture confined away from a nearby water or gas zone. This knowledge would allow either proceeding with the treatment with confidence of its economic success, or taking additional actions, e.g. re-design or repeat the special pumping procedure and materials to ensure better success at staying away from the water zone.

[0025] Among the "passive" materials, metallic particles may be used. These particles may be added as a "filler" to the proppant or replaces part of the proppant, In a most preferred embodiment, metallic particles consisting of an elongated particulate metallic material, wherein individual particles of said particulate material have a shape with a length-basis aspect ration greater than 5 are used both as proppant and "passive" materials..

[0026] Advantageously, the use of metallic fibers as proppant contributes to enhance proppant conductivity and is further compatible with techniques known to enhance proppant conductivity such as the use of conductivity enhancing materials (in particular the use of breakers) and the use of non-damaging fracturing based fluids such as gelled oils, viscoelastic surfactant based fluids, foamed fluids and emulsified fluids.

[0027] Where at least part of the proppant consists of metallic In all embodiments of the disclosed invention, at least part of the fracturing fluid comprises a proppant essentially consisting essentially of an elongated particulate metallic material, said individual particles of said particulate material have a shape with a length-basis aspect ration greater than 5. Though the elongated material is most commonly a wire segment, other shapes such as ribbon or fibers having a non-constant diameter may also be used, provided that the length to equivalent diameter is greater than 5, preferably greater than 8 and most preferably greater than 10. According to a preferred embodiment, the individual particles of said particulate material have a length ranging between about 1mm and 25mm, most preferably ranging between about 2mm and about 15mm, most preferably from about 5mm to about 10mm. Preferred diameters (or equivalent diameter where the base is not circular) typically range between about 0.1mm and about 1mm and most preferably between about 0.2mm and about 0.5mm. It must be understood that depending on the process of manufacturing, small variations of shapes, lengths and diameters are normally expected.

[0028] The elongated material is substantially metallic but can include an organic part for instance such as a resin-coating. Preferred metal includes iron, ferrite, low carbon steel, stainless steel and iron- alloys. Depending on the application, and more particularly of the closure stress expected to be encountered in the fracture, "soft" alloys may be used though metallic wires having a hardness between about 45 and about 55 Rockwell C are usually preferred.

[0029] The wire-proppant of the invention can be used during the whole propping stage or to only prop part of the fracture. In one embodiment, the method of propping a fracture in a subterranean formation comprises two non-simultaneous steps of placing a first proppant consisting of an essentially spherical particulate non-metallic material and

placing a second proppant consisting essentially of an elongated material having a length to equivalent diameter greater than 5. By essentially spherical particulate non-metallic material it is meant hereby any conventional proppant, well known from those skilled in the art of fracturing, and consisting for instance of sand, silica, synthetic organic particles, glass microspheres, ceramics including alumino-silicates, sintered bauxite and mixtures thereof or deformable particulate material as described for instance in U.S. Patent No. 6,330,916. In another embodiment, the wire-proppant is only added to a portion of the fracturing fluid, preferably the tail portion. In both cases, the wire-proppant of the invention is not blended with the conventional material and the fracture proppant material or if blended with, the conventional material makes up to no more than about 25% by weight of the total fracture proppant mixture, preferably no more than about 15% by weight.

<u>Experimental Methods</u>

[0030] A test was made to compare proppant made of metallic balls, made of stainless steel SS 302, having an average diameter of about 1.6mm and wire proppant manufactured by cutting an uncoated iron wire of SS 302 stainless steel into segments approximately 7.6mm long. The wire was about 1.6mm diameter.

[0031] The proppant was deposited between two Ohio sandstone slabs in a fracture conductivity apparatus and subjected to a standard proppant pack conductivity test. The experiments were done at 100°F, 2lb/ft^2 proppant loading and 3 closure stresses, 3000, 6000 and 9000psi (corresponding to about 20.6, 41.4 and 62MPa). The permeability, fracture gap and conductivity results of steel balls and wires are shown in Table 1.

Table 1.

Closure Stress (psi)	Permeability (darcy)		Fracture Gap (inch)		Conductivity (md-ft)	
	Ball	Wire	Ball	Wire	Ball	Wire
3000	3,703	10,335	0.085	0.119	26,232	102,398
6000	1,077	4,126	0.061	0.095	5,472	33,090
9000	705	1,304	0.064	0.076	3,174	8,249

[0032] The conductivity is the product of the permeability (in milliDarcy) by the fracture gap (in feet).